Flip Chip Assembly for Sub-millimeter Wave Amplifier MMIC on Polyimide Substrate

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Abstract — The sub-millimeter wave amplifier MMIC with flip-chip mounting on polyimide substrate has been realized. The thickness of the substrate and the pitch of GND vias are designed to suppress the air radiation from the slot pattern in the substrate. The test results of the micro-strip line formed on the polyimide substrate shows that the design is applicable to the assembly operated up to 320 GHz. The InP HEMT amplifier MMIC with the assembling technique achieved the operation in 240–260 GHz frequency band with the gain of 20 dB.

Index Terms —InP, HEMT, sub-millimeter, flip chip.

I. Introduction

The broad atmospheric window between 200 and 300 GHz [1] is attractive for radio astronomy, imaging sensors, and multi-10 Gigabit wireless communications due to the high available absolute bandwidths. Sub-millimeter-wave monolithic integrated circuits (MMICs) based on InP or GaAs metamorphic high electron mobility transistor (HEMT) will enhance the capability of these applications [2-7]. In sub-millimeter-wave band, not only MMIC but also chip assembly should be carefully designed. Because the wave length of signal becomes close to 100 µm, the design to bond the chip and the substrate affects on RF performances significantly. Therefore, a conventional face-up mounting of chip or a wiring technique cannot be used in this frequency band.

In this paper, we report the feasibility of flip chip assembly in sub-millimeter wave band. A suitable GND pattern for chip mounting board is discussed based on simulation and measurement. The measurement results of the flip chip mounting MMIC amplifier are presented as well.

II. FLIP CHIP ASSEMBLY

A. Chip assembly methods

First, the module image for sub-millimeter wave application we considered is shown in Fig.1. Figure.1a indicates the top view of the module image and its cross-sectional view along line (A-A') comprised of InP MMIC, printed substrate and micro-strip line (MSL) waveguide transducer. In order to achieve high gain, the use of a metal horn antenna is considered. The MMIC is mounted on the printed substrate. The interface between the MSL and the antenna can be realized by the conventional back-short structure shown in the figure. There are two types of the chip mounting on the board in sub-millimeter wave band. First, the face-up mounting using through-substrate via as shown in Fig.1b [2,3]. With this type, the substrate thickness of the InP chip should be thinner than 50 µm to avoid undesired millimeter wave propagation in the substrate. As a result, the mechanical strength of the InP chip decreases, and the yield ratio of fabrication process goes down. Therefore, we choose the flip chip mounting, as shown in Fig.1c. A micro-strip line structure is employed for interconnection in the circuit. Two metal layers are assigned for signal and GND. The GND metal layer shields the electrical field spread to the InP substrate. Au ball bumps are

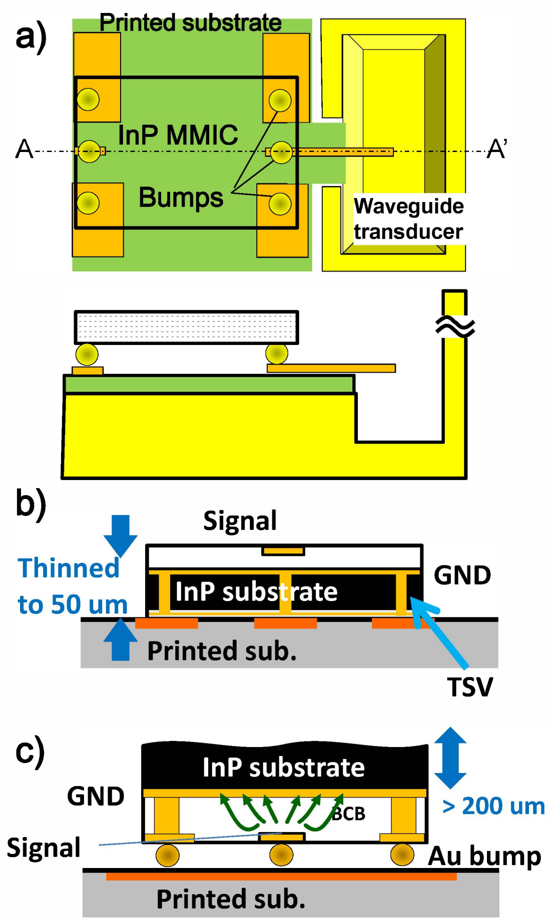

Fig. 1 a) Top and cross-sectional view of module image, b) face-up mounting, and c) flip chip mounting.

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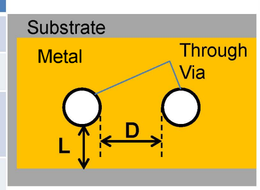
used to bond a chip and a printed substrate. The insulator film on the chip is a few um thick, and this is sufficiently thin compared with the distance between the chip and the printed substrate (typically 50 μm). Therefore the most electrical field concentrates in the chip. The influence of the electrical coupling between the chip and the substrate can be negligible. Table 1 shows the comparison of a dielectric constant, a tan-δ, a loss, and design rules for a quartz substrate and a polyimide substrate. L means the distance between metal edge and through via, and D means the pitch of vias. The quartz is desirable for the substrate in terms of loss. However, the design rule for vias is not fine compared with that of the polyimide. Since the quarter wavelength (λ/4) of the signal in the substrate becomes less than 200 μm at sub-millimeter band, the influence of the length of L and D should be considered for designing the substrate. We discuss the design in the next section.

Table 1 Comparison of low loss substrates

	Quartz	Poly-imide
εr	3.5	3.5
Tan δ	0.03	0.05
Loss [dB/mm]	2	3
L / D[μm]	200 / 200	20 / 50



B. Feasibility of flip chip on polyimide substrate

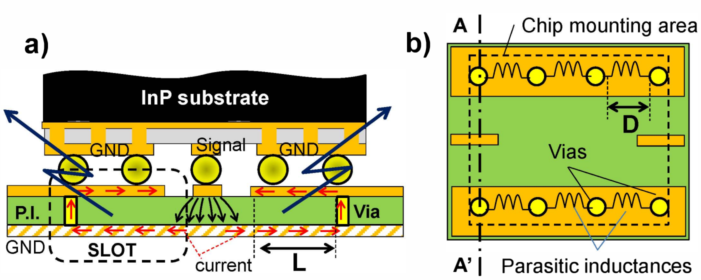


Fig2. a) Cross sectional view, and b) top view of substrate

The discontinuous GND connection between chip and substrate causes the signal radiation to the air. Fig.2a and 2b show the cross sectional view of the flip chip mounting and the top view of the substrate, respectively. As indicated with the dashed line, the slot is formed between the top GND and the bottom GND of the polyimide substrate. The radio signal whose wavelength is four times of the L between the edge of GND and the through vias, is radiated from the slot. The space D between the two through vias also affects the loss of the substrate. Because the GND patterns on the top metal layer have some inductances, the large space of the vias makes the GND non-ideal. By using the electro-magnetic simulation, we calculated the impact of L and D on the loss.

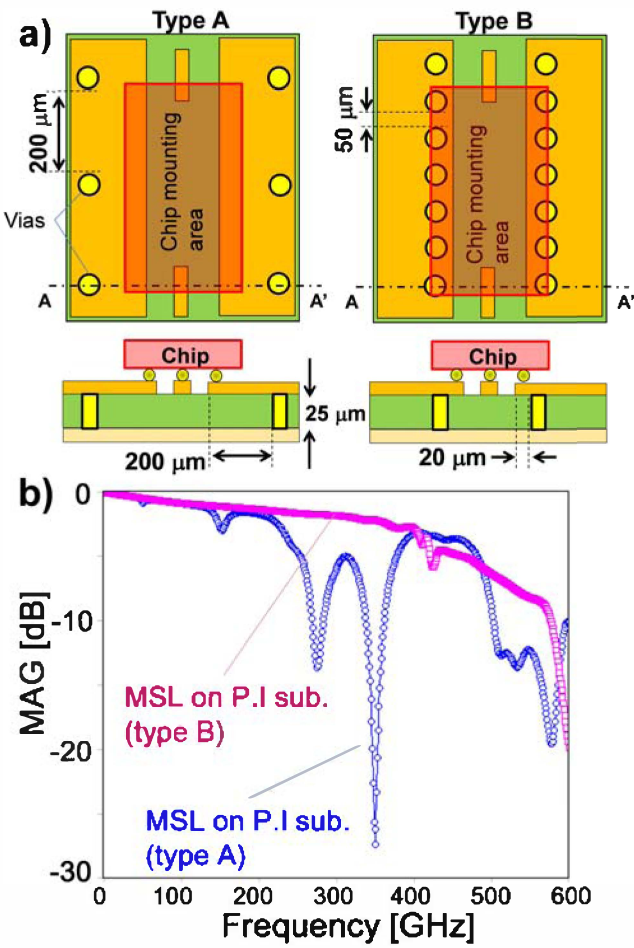


Fig. 3a) Substrates of type A and B, and b) simulation results.

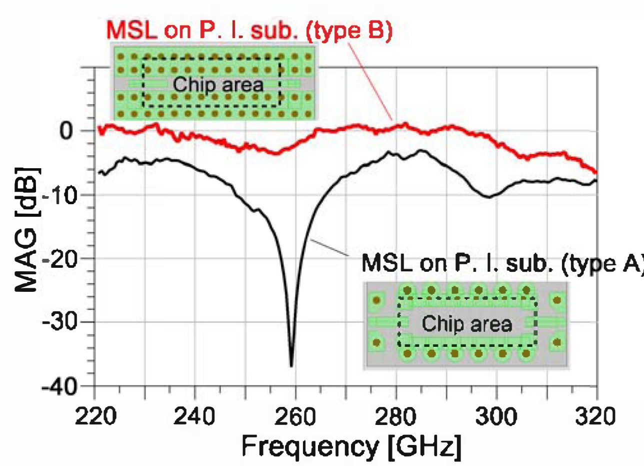


Fig. 4 Measurement results.

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Fig.3a shows the top and the cross-sectional views of the flip chip module used for the calculation. Fig.3b shows the simulated results. We compare two types of the substrate named type A and type B. The type A is the coarse pattern having *L* and *D* of 200 μm. On the other hand, the type B is the fine pattern designed using the minimum value of *L* and *D* in the design rule of the polyimide. In regard to those patterns, we calculated the maximum available gain (MAG) defined by the following equations;

$$MAG = |S21|/|S12| \{K - (K^2-1)^{1/2}\} \quad (1)$$
$$K = (1+|D|^2-|S_{11}|^2-|S_{22}|^2) / (2|S_{12}S_{21}|) \quad (2)$$
$$D = S_{11}S_{22} - S_{12}S_{21} \quad (3)$$

The thickness of the substrate is 25 μm, and the diameter of the ball bump is 50 μm. As shown in the graph, the MAG line of type A has the large dips around 300 GHz because of the slot mode radiation. Since the dip is same as the resistive loss, it cannot be eliminated by changing the impedance matching to the input and output nodes. On the other hand, type B has small insertion loss up to 400 GHz, and the dip exists in the line of type A is not observed.

Next, to confirm the simulated results, we fabricated the samples of the flip chip mounted MSL for both substrates of type A and B. The polyimide was used for the substrate. Fig.4 shows the measured MAG of the fabricated samples. The MAG lines of the flip chip mounted MSL on type A (black line) and B (red line) are plotted in the figure. The flip chip mounted MSL on type A has quite large dip around 260 GHz. On the other hand, the MAG line of MSL on type B has almost flat characteristic in the broadband. Those results support the simulation and clearly indicate that it is required to minimize the size of L and D of substrate to achieve the performance of the module. Therefore, we chose the polyimide substrate for the flip chip mounting in the sub-millimeter wave band.

III. Measurement Results of MMIC

We developed the flip chip mounted MMIC and measured the RF performances. Fig.5a shows the circuit diagram of the amplifier MMIC comprised of the 6-stage common-source amplifiers [8]. The amplifier MMIC was fabricated in 75 nm InP HEMT technology with three Au metal layers and BCB thin films. *L* and *D* in the polyimide substrate were designed in the same manner we discussed in above section. Fig.5b and 5c show the photographs of the flip chip mounted MMIC and the cross-sectional view. The polyimide substrate is mounted on the metal plate with the conductive paste. The height of the ball bumps are about 40 μm. Fig.5d shows the measured S-parameters (S_{11}, S_{21}, S_{22}). The dashed line is the result of the MMIC bare chip, and the solid line is that of the flip chip mounted MMIC. The gain was about 20 dB in the frequency range of 240 – 260 GHz, and frequency characteristics has not been changed. In our knowledge, this is the first result of the flip chip mounted MMIC in the sub-millimeter wave band.

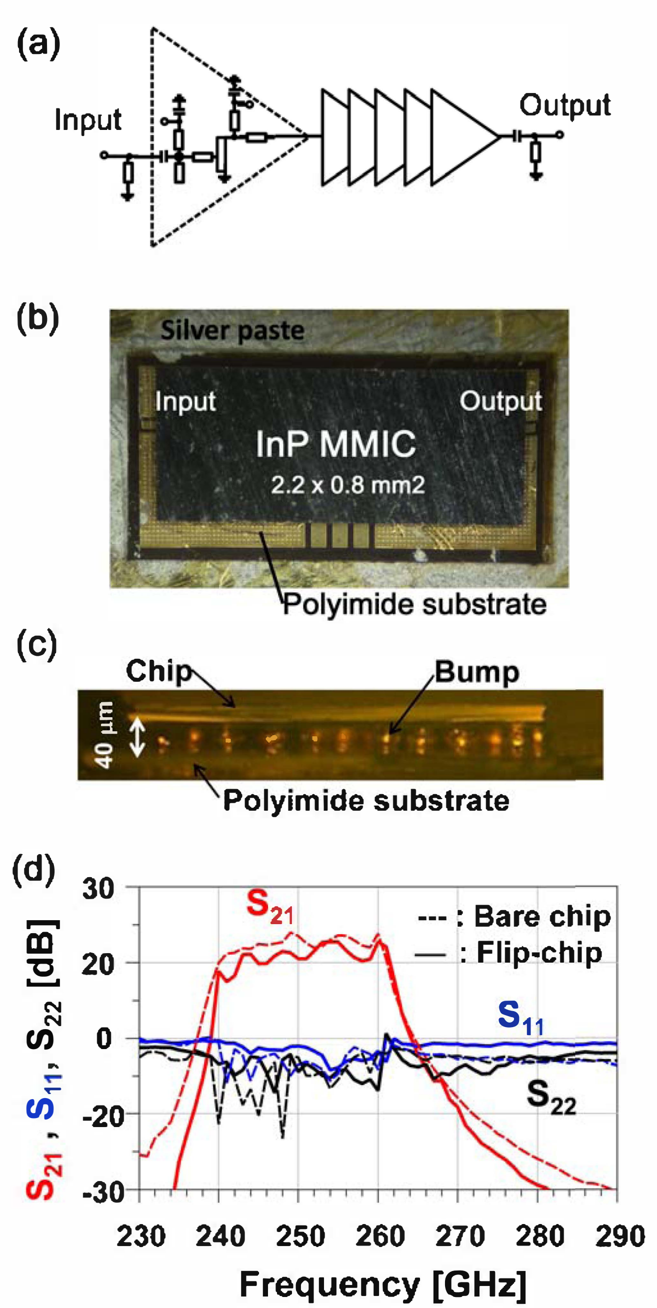

Fig.5 a) Circuit diagram of the 6-stage amplifier, b) photo of the flip chip mounted MMIC, c) cross-sectional view, and d) measured S-parameters.

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IV. Summary

The feasibility of the flip chip mounting on the polyimide substrate in the sub-millimeter wave band was described. It was demonstrated the distance between metal edge and through via (L) and the pitch of vias (D) were required to minimize in order to avoid the loss degradation. From view of the loss, the polyimide was the optimum substrate for the flip chip mounting in the sub-millimeter wave band. The flip chip mounted amplifier MMIC successfully demonstrated the gain of more than 20 dB in 230 – 260 GHz and frequency band characteristics without any shift by the chip mounting. Those results increase the possibility for sub-millimeter wave applications using the flip chip assembly.

Acknowledgement

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